RF Exposure Due to Mobile Devices Operated Close to the Human Body

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***Abstract* — The SAR (Specific Absorption Rate) simulations due to mobile devices operated in close range to the human head and body are described in this paper. The FDTD (Finite-Difference Time-Domain) numerical method together with realistic children, adolescents and adults' models are employed to estimate the 1 g and the 10 g SAR in different biological tissues. Typical mobile phones, laptops, tablets and virtual reality glasses were considered and the alternatives to reduce the SAR are discussed. The need of new dosimetric parameters and skin and nervous system models for 5G and millimetric waves exposure are also addressed.**

***Keywords* — Radiofrequencies (RF) dosimetry, Specific Absorption Rate (SAR), Mobile Phones, Laptops, Tablets, Virtual Reality glasses.**

I. Introduction

Since in many countries there is a widespread use of wireless transmitting devices by children, adolescents and adults very close to their head and body and sometimes for long time, it is important to assess the RF absorption in different tissues in order to estimate the associated health risks. The available international recommendations limit the SAR (Specific Absorption Rate) in 1.6 W/Kg (in 1 g, FCC [1], IEEE/ANSI [2]) or 2 W/Kg (in 10 g, ICNIRP [3]). They consider only short-term effects (i.e. "thermal" effects) while many peer reviewed scientific papers have demonstrated health risks for long time exposure well below those limits ("non-thermal" effects) [4, 5].

In 2011, IARC classified radiofrequencies (RF) radiation as a "possible human carcinogen" (group 2B) [6]. This includes RF radiation from base stations, mobile phones, laptops, tablets, and other transmitting devices. Due to subsequent epidemiological findings [4, 7 - 9], some independent scientists [4, 5] recommended that these results merit IARC reclassification to 2A ("probably human carcinogen").

Due to the introduction to the 5 G technologies, the use of RF and millimetric waves will increase. Therefore, the revision of the exposure standards and guidelines will be required. Then, the current SAM certification process should be complemented with electromagnetic field (EMF) exposure computer simulations.

In this paper the SAR simulations due to the operation of mobile phones, laptops, tablets and virtual reality (VR) glasses close to the head and the body are summarized.

II. Methodology

The FDTD method (SEMCAD X 14.8 software from SPEAG and CST-Studio from Dassault) together with realistic human models for different ages [10] and a Specific Anthropomorphic Mannequin – SAM [11] are employed.

The dielectric parameters for the adults were obtained from the work of Gabriel [12] which are regularly used for this purpose in medical applications. The age specific parameters for children were estimated based on accepted methods by correlating age specific measurements in pigs [13] with Gabriel data [12] and interpolating as described in [14].

III. Mobile Phones

A dual band (900 MHz and 1800 MHz) model was used [15], with a common cell phone case 109 × 60 × 13.9 mm and a Planar Inverted "F" Antenna (PIFA) in the top position.

Fig. 1 shows the psSAR (peak spatial SAR) averaged over cubic volumes containing 1 g and 0.1 g, relative to the psSAR computed over 10 g of continuous tissue for a 900 MHz mobile phone exposure. The head including and excluding pinna, and brain psSAR values for the SAM phantom and the average results for 10 anatomical models are presented [14].

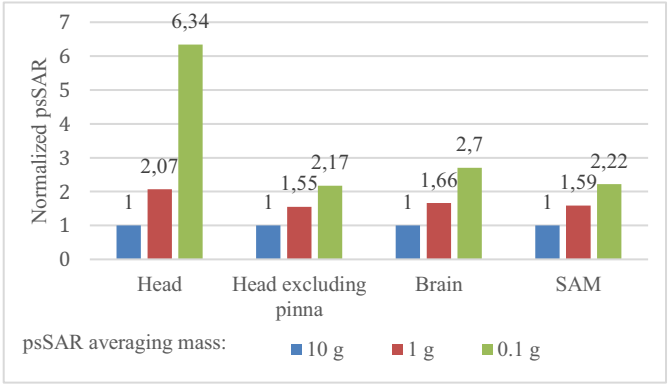

Fig. 1. psSAR averaged over cubic volumes (containing 1 g and 0.1 g) normalized to the psSAR over 10 g of continuous tissue [14].

Consistent with previous reports [16] the averaging volume employed in the modelling is correlated inversely with the calculated maximum tissue dose or psSAR (Fig. 1). Averaging the SAR over 10 g of tissue with a 2 W/kg maximum SAR (consistent with the ICNIRP recommendation) allows over 2-fold greater radiation absorption in the head compared with

averaging over 1 g of tissue with a 1.6 W/kg maximum SAR (consistent with current FCC/FDA methods). Furthermore, averaging SAR over 0.1g – one-tenth the smallest mass in current use – yields a tissue dose up to 6 times that calculated for the commonly used 10 g mass standard.

These differences could be relevant since at the frequencies planned to be used in the 5 G, the EMF is absorbed in the first few millimeters from the surface, then cubes of 1 g or 10 g (with dimensions close to 1 to 3 cm) will be inadequate to assess exposure. Also, more precise models of the skin (e.g. including the helical sweat ducts) should be of interest.

Fig. 2 shows the 1 g psSAR in the skull, brain, hippocampus, cerebellum and eyes at different age models.

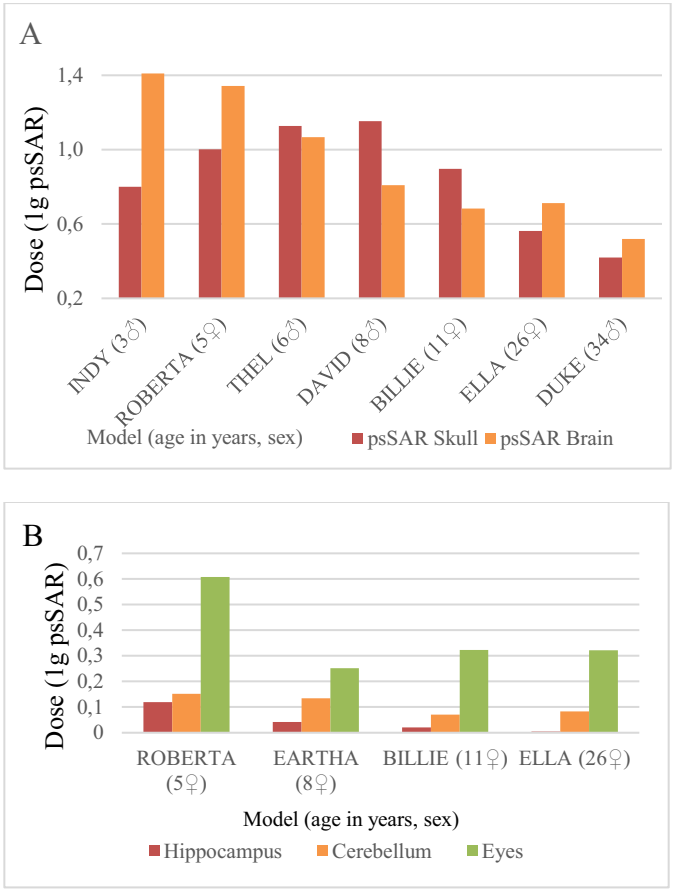

Fig. 2. psSAR in 1g of specific tissues. A. the skull and brain and B. specific tissues in models with these features identified – hippocampus, cerebellum and eyes [14].

As shown in Fig. 2, with the phone against the ear, the psSAR in the hippocampus and the cerebellum is greater in the younger models, with approximately 2-fold greater psSAR in the cerebellum, and even greater psSAR difference in the hippocampus. Also, the eyes are particularly vulnerable to RF radiation, as a result of little fluid circulation and thus poor cooling, plus high RF radiation absorption as a result of relatively high water content. As shown in Fig. 2, the eyes in the youngest models absorb between 2-fold and almost 5-fold higher doses of RF radiation than those of the older models.

Fig.3 shows the trend of psSAR in 1 g of grey matter, as a function of distance from the antenna to the brain.

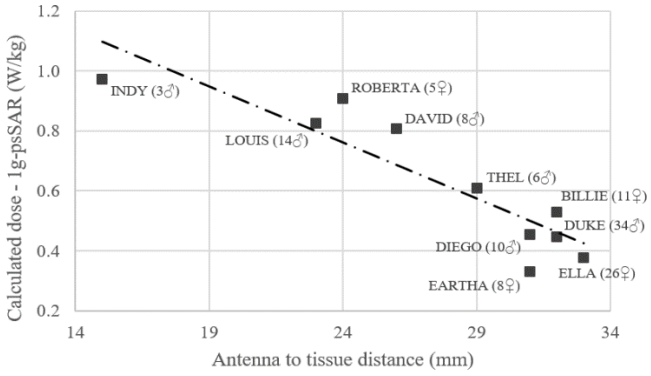

Fig. 3. Trend of psSAR in 1g of grey matter, as a function of distance from the antenna to the brain, for phone in "talk" position [14].

It can be observed that the psSAR in the grey matter as a function of distance from the antenna (i.e. the pinna plus the skull widths), depicts a clear trend of decreasing psSAR with increasing distance (as expected) and illustrates the trend amongst models. Substantial inter-individual variation in psSAR is seen in the more than two-fold difference between the David and Eartha models, both 8 years of age.

Therefore, when measuring the exposure of specific tissues, the distance effect increases the SAR result in smaller models, such as in the children models. This should be considered in the standard revisions.

IV. Laptop Computers

The SAR is estimated in the body of a seated 34-years-old male exposed to 2.4 GHz electromagnetic field (EMF) emitted by laptops. The laptop position is varied vertically from the seated model in order to estimate the changes in SAR associated with changes in distance from the body. A half wave dipole antenna and a planar inverted "F" antenna (PIFA) operating at 2.4 GHz are used in the simulations. The power delivered to the radiating elements was normalized to 100 mW. The antennas were located in the right rear part of the screen and on the right rear part of the keyboard.

Fig. 4 shows the SAR distribution with three distances between laptop and lap (0, 10, 20 cm respectively) for a PIFA.

Fig. 4 - SAR distribution when the PIFA is behind the keyboard: (a) notebook on the lap, (b) notebook at 10 cm from the lap and (c) notebook at 20 cm from the lap.

As is shown in Fig. 4 when the notebook is on the lap, the parts closer to the radiating elements, such as the hands and the laps of the model, absorb higher EMF intensities.

Table 1 - Simulated psSAR values (in W/Kg) with antenna behind keyboard and microcomputer is moved vertically from the lap.

Antenna and distance	psSAR 1g (W/kg)	psSAR 10g (W/kg)
PIFA on the lap	1.40	0.67
PIFA 10 cm from the lap	0.56	0.36
PIFA 20 cm from the lap	1.01	0.55
Dipole on the lap	3.02	1.36
Dipole 10 cm from the lap	0.30	0.20
Dipole 20 cm from the lap	0.31	0.20

The psSAR levels shown in Table I with the dipole are below the limits recommended in [3] for 10 gram cubes, but for 1 gram cubes the psSAR is above the limit recommended in [1]. The psSAR with the PIFA is always below the limits recommended in [1] and [3].

V. Tablets

An analysis of the interaction of the electromagnetic field generated by a tablet with three different models of human heads: a homogeneous model (SAM) and two heterogeneous models (an adult man, "Duke", 34-years-old and a child, "Thelonious", 6-years-old) was described in [18]. A tablet was simulated at 2.45 GHz assuming 30 mW normalized radiated power. The distance between the eye lens of the head models and the tablet's screen centre was 50 mm, 100 mm, 150 mm and 200 mm. The 10 g and 1g psSAR were estimated and are shown in Table 2.

Table 2 - psSAR over 10g and 1g (mW/kg) [18]

	SAM Phantom		Adult Head (Duke)		Children Head (Thel.)	
	SAR 1g	SAR 10g	SAR 1g	SAR 10g	SAR 1g	SAR 10g
50mm	39.6	26.1	18.9	10.8	35.2	26.4
100mm	11.8	8.1	9.4	4.8	11.3	8.3
150mm	7.5	4.2	7.4	3.3	10.2	4.3
200mm	5.4	2.6	5.2	2.1	7.0	3.0

Fig. 5 shows SAR distribution in the head models, normalized to 0.04 mW/g = 0 dB, with a 30 dB color scale for the SAM Phantom at distances of 50 mm (a); 100 mm (b); 150 mm (c) and 200 mm (d); 34 y-o model "Duke" at distances of 50 mm (e); 100 mm (f); 150 mm (g) and 200 mm (h); 6 y-o model "Thelonious" at distances of 50 mm (i); 100 mm (j); 150 mm (k) and 200 mm (l).

In the simulations for 1g of tissue psSAR the homogeneous SAM phantom head model presented slightly higher levels at distances of 50 mm and 100 mm, on the other hand at

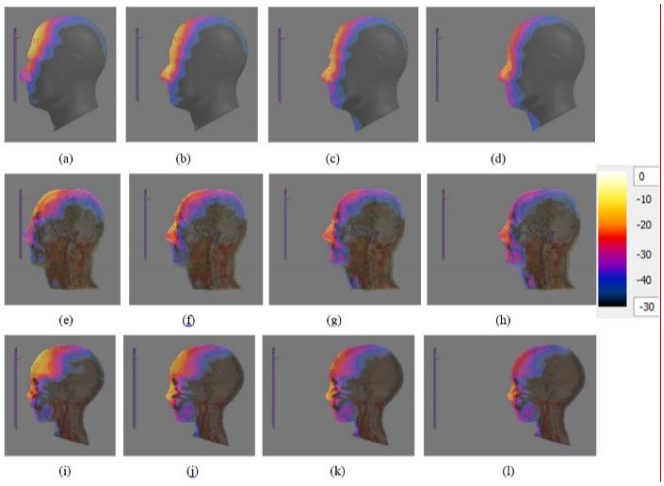

Fig. 5 - SAR distribution in the head models, normalized to 0.04 mW/g = 0 dB, with a 30 dB color scale.

distances of 150 mm and 200 mm the heterogeneous children model presented higher levels. This is a distance effect, since the antennas (red cones in Fig.5) are placed on the top of the tablets. The antenna is located above the anthropomorphic models' head but in front of the SAM forehead (since the SAM is an oversized head) and this has an effect for small distances.

VI. Virtual Reality

The differences between doses of RF radiation (SAR) in critical components of the brain of the child and adult shown in [14] are clearly illustrated in Fig. 6, in child ("Thelonious") and adult ("Duke") head models, when the phone is used for talking, or for viewing virtual reality.

In Fig. 6 the SAR in cross-sectional views of child and adult male heads, with phone in talk and in virtual reality positions are shown: (A) Axial slices (top view) of "Thelonious" (6-years-old) and "Duke" (34-years-old), with cell phone in cheek position, intersecting the eyes; (B) Axial slices (top view) of "Thelonious" and "Duke", with cell phone in virtual reality position, intersecting the eyes; (C) Quasi-coronal slices (frontal view) of "Thelonious" and "Duke" with cell phone in the cheek position, through the ear; (D) Parasagittal slices (side view) of "Thelonious" and "Duke", with cell phone in virtual reality position, intersecting the eye. The scale is 50 dB with 0 dB=1.6 mW/g.

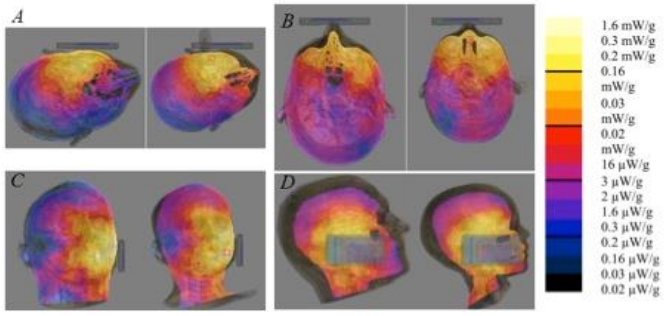

Fig. 6 - SAR in cross-sectional views of child and adult male heads, with phone in talk and in virtual reality positions. The scale is 50 dB with 0 dB=1.6 mW/g [18].

It can be observed that the eyes and frontal lobe of the 6-years-old model experiences a roughly 3-fold higher psSAR than in the adult's eyes and frontal lobe, when a virtual reality glasses containing a phone is placed directly in front of the eyes. This is also mainly due to a distance effect. Deeper absorption penetration is also observed (Fig.6.).

VII. Discussion and Conclusions

The SAR for some typical mobile phones, laptops, tablets and virtual reality glasses were simulated and results were compared to the available recommended exposure guidelines. It was observed that when some of these devices are operated very close to the head or body the simulated results can be above the exposure limits. This is particularly the case for the children models and for particular tissues (e.g. hippocampus and cerebellum). Then the methods to determine regulatory compliance for wireless devices should be re-examined.

Antennas now used in portable devices are monopole, helix, PIFA or other planar structures (generally without ground plane) and they radiate the EMF almost to all directions. Since these devices can be operated close to the head or body, directional antennas radiating the EMF to the direction opposite to the head and body should be developed in order to reduce the SAR in these tissues. This can also contribute to reduce antenna input impedance mismatching when the device is operated close to the body. New antenna techniques including a back plane, electromagnetic band gap (EBG) and artificial magnetic conductor (AMC) could be adequate alternatives aiming to reduce the SAR in the user's head and body. There is also an urgent need for research to evaluate the risks to the eye from use of cell phones in virtual reality applications.

Also, in the near future the use of mm-waves (e.g. 26 GHz and above) will be widespread to carry new services on the 5 G network. Then, the need for new quantities of interest, metrics and exposure limits adequate for these frequencies, as well as modelling new structures, such as the skin and the nervous system, are suggested.

It is very important to remark that the recommendations and the standards usually adopted in different countries only consider the health effects of short time exposure. However, the mobile phones, notebooks, tablets and virtual reality glasses may be used for long time very close to the user's body. Then the long-time health effects must be taken into consideration in order to evaluate the health risks. Meanwhile the Precautionary Principle should be adopted in order to reduce health risks.

Acknowledgments

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